

# **Independent Technical Assessment of NASA and External Quantum Sensing Capability**

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## **Executive Summary**

- The Subject Matter Experts in the Sensors & Instrumentation Quantum Sensing Community of Practice (CoP) requested an independent technical assessment of the agency's capabilities in QS to understand NASA's internal needs and competencies related to QS and compare agency capabilities with those available externally including industry, academia, and other government agencies.
- The outcomes of the assessment will help the agency in establishing appropriate strategies and investments to develop and maintain the state-of-the-art sensing competence and capabilities required to meet the agency's future needs.
- NASA Engineering and Safety Center Review Board approved the assessment request and assigned NASA Technical Fellow to lead and conduct the assessment by engaging NASA Centers, NASA HQ and an independent, non-commercial, and highly credible Quantum Sensing Experts from Academia, Department of Defense, other Government Agencies. The assessment duration is for one year, starting October 2021 and ending December 2022.

## Background

- Quantum Sensing is an integral part of National Quantum Information Science initiative 2020.
- Many quantum sensors are already being developed in various NASA centers, scattered in different Science Mission Directorate (SMD) technology development programs.
- Quantum properties are well recognized and demonstrated for their potentials to improve existing measurement systems and enable new ones.
- Sensing is critical to NASA missions and space exploration. Sensors in the future cannot avoid quantum systems.
- Global investments in quantum technology are intense and competitions are fierce, and the U.S. needs to be at the forefront of it.
- **Space applications are unique and specialized. NASA will have to take a lead to ensure future sensors will meet ever demanding needs.**

## Background

- The recent FY 2020 federal Research and Development Budget Priorities memo addresses the leadership need in Quantum Information Science (QIS) directing agencies to “prioritize QIS research and development (R&D), which will build the technical and scientific base necessary to explore the next generation of QIS theory, devices, and applications.” QS is an integral part of QIS. **NASA is a key part of the directive to forward American space exploration and commercialization by providing “capabilities that have broad potential applications in space and on Earth.”** QS provides an arena for NASA to demonstrate leadership in both areas of the administrative directive.
- QS uses quantum properties to achieve unprecedented measurement sensitivity and performance, including quantum-enhanced methodologies that outperform their classical counterparts. Typical quantum sensors exploit techniques such as atomic systems, matter waves, quantum entanglement, quantum superposition of states, quantum illumination methods, and manipulation of photons and atoms, in general. **Guided by advancements in our ability to generate, manipulate, and control quantum systems, the emerging quantum sensing technologies promise unrivaled sensitivity, resolution, and precision, potentially leading to game-changing applications.** Significant gains include technologies important for a range of NASA missions such as remote sensing, *in situ* measurements, metrology, interferometry, quantum communication, ranging, imaging, radar and lidar receivers, and gravity measurements.

## Problem Description

QS, that is, sensing approaches based on quantum properties, has been rapidly recognized as a future direction for new and improved sensing capabilities under the general field of quantum information science. Significant R&D efforts around the world have been focusing on QS space applications because of the unique space environment for implementing QS and challenges in meeting space science goals. [For NASA to lead the application of QS in space and to better meet the challenges for future space science and exploration missions, the agency needs to understand the QS direction \(technology\), its potential for future space missions \(value\) and existing capabilities against its needs \(strategy\).](#)

NASA utilizes a broad spectrum of sensors and associated instruments supporting science missions, both manned and unmanned exploration missions, and the associated support systems and infrastructure for such missions. NASA investigators are seeking to provide significant gains in sensor applications to advance NASA missions by developing new types of detectors with improved sensitivity, resolution and precision. Because of the needs for supporting future NASA programs, many of the centers have started various levels of QS development activities. [Therefore, NASA seeks to understand its internal competencies related to QS and compare agency capabilities with those available externally including in industry, academia, and other government agencies.](#)

## Approach

- An independent, non-commercial, and highly credible technical assessment team is required to provide NASA leadership and practitioners with an assessment on the technology, value, and identify capabilities, internal and external to NASA, to **lead, leverage and collaborate** to meet NASA current and future needs. The outcomes of the study will help the agency to establish appropriate strategy and investments to develop and maintain the state-of-the-art sensing competence and capabilities to meet the NASA's future needs for science and exploration.
- The assessment team will collaborate with HQ, NASA Centers and the representatives in the CoP to obtain common, current understanding of agency mission needs where QS can be an important enabler for future needs, and any programs, projects, assets, and technologists working in QS.
- The assessment team will organize a Quantum Sensing Workshop of practitioners from industry, academia, other government agencies, external experts, and interested NASA personnel to gather the assessment information.
- The assessment team will conduct information gathering on the industry at large, educational institutions, and other government agency research efforts for capture in the assessment database.
- The assessment team will develop findings and conclusions describing NASA's capabilities for the mission needs, NASA's relative position on new, enabling technologies, and an analysis of the gaps that may present any risks to near-term or far-term mission needs.

## Tasks and Scope of Assessment

- QS is a new and emerging field. To ensure NASA have the appropriate capabilities to meet future space mission and exploration needs, the agency must have a correct assessments of its needs, capabilities and gaps, and appropriate strategy to help foster, develop, and establish the right capabilities, for both short- and long-term need, and help NASA's mission successes in the coming decades.
  - Task 1: Develop a methodology to assess NASA's current QS capabilities at the centers and their ability to impact the relevant mission customers:
    - The Panel shall develop a process definition, deliverables, and implementation schedule consistent with the broad assessment objectives and NASA directives.
    - The Panel shall develop an assessment template/scorecard format and criteria for reporting and presentation. The template/scorecard shall be capable of storing data in a standard electronic format such as Excel or Access. The template/scorecard shall contain the following items, at a minimum:
      - Fields to record a description of the center technology currently on-going, a determination of the current technology readiness level (TRL), a description of expected performance parameters for the technology, a description of the driving Mission Directorate need, and a description of any near-term or long-term impediments to advancing the technology discovered;
      - Fields to record where this technology stands with respect to other centers, industry, academia, and other government agencies.

## Tasks and Scope of Assessment

- Task 2: Conduct internally and externally sourced information review to establish the assessment knowledge base:
  - The Panel shall coordinate/collaborate with Quantum Sensing Tiger Team (QSTT) (NASA HQ and relevant center representatives) to obtain common, current understanding of agency mission needs where QS can be an important enabler for future needs, and any programs, projects, assets, and technologists working in QS sufficient to gather the required data for Task 1.
  - The Panel shall investigate and assess the application or potential applications of QS to missions at NASA with a differentiation between near-term needs and long-term needs. The mission study shall include currently approved mission needs and mission concepts under development such as
    - Atomic clocks for position and science sensing
    - Atomic quantum inertial and gravity measurement systems
    - QS for ascertaining material properties
    - Astronomy/astrophysics/fundamental physics probes
    - Quantum receivers in radar and lidar
    - Quantum-linked sensing arrays and telescopes
    - Single photon (microwave and optical) detector systems
    - Chip-scaled magnetometers
    - Quantum optics imaging
  - The Panel should identify specific applications and measurements relative to NASA science missions, exploration missions and industry needs that would benefit from low TRL development of quantum sensing.
  - The Panel shall leverage appropriate QSTT Members and civil servant personnel at HQ/Centers as necessary.
  - The Panel shall utilize readily available heritage (e.g., Technical Capabilities Assessment Team, Agency Capability Assessment) and current NASA Technical Fellow-related documents.

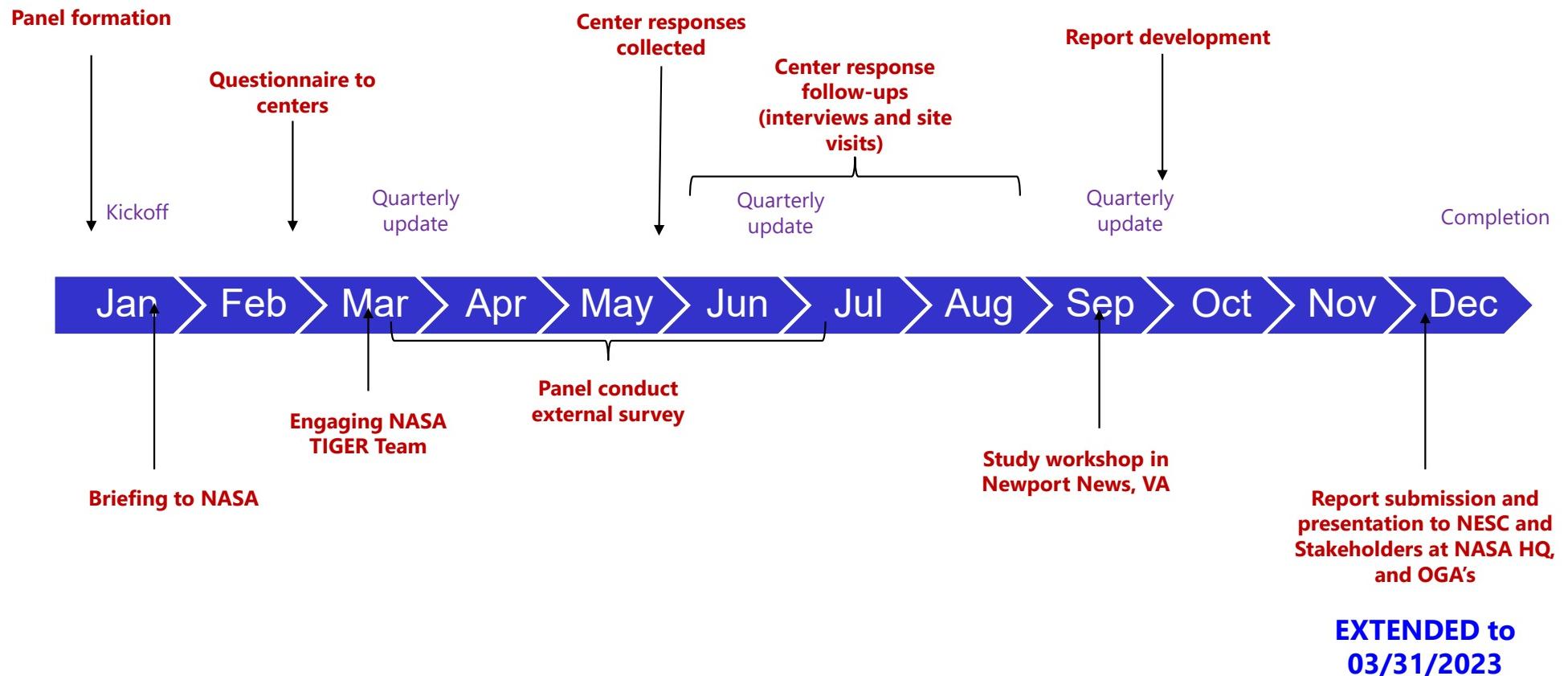
## **Tasks and Scope of Assessment**

- Task 3: The Panel shall assess NASA and External QS capabilities and identify technology gaps, synergies and leveraging opportunities for NASA and partnership opportunities with industry in advancing the TRL of critical QS technologies. The data will be gathered from NASA-sponsored Quantum Sensing Workshop, targeted to bring NASA QS practitioners from centers, NASA HQ personnel, industry, academia, federally funded research and development centers and other government agencies.
- Task 4: The Panel shall gather assessment information via interviews, site visits, or telemeetings to HQ/centers and other organizational entities; this information shall be collected in the electronic template/scorecard of Task 1.
- Task 5: The Panel shall conduct research on the industry capability, at large, including the private sector, educational institutions and other government agency research facilities. This information shall be relatable the information and shall be collected in the electronic template/scorecard of Task 1.
- Task 6. The Panel shall develop findings and conclusions, including lessons learned and suggested improvements, that describe NASA's state of capability relative to the near-term and far-term mission needs, examples of where NASA is ahead of its peers or working on new, enabling technology, and examples of where NASA is lagging its peers.
- Task 7. The Panel shall provide an analysis of the gaps between the industry and agency and how these gaps present any risks to near-term, or far-term mission needs and shall recommend a list of possible solutions on how to close the gap(s)
- Task 8. The Panel shall make recommendations, based on their analysis, of the most enabling QS areas in short- and long-term for NASA to focus on.
- Task 9. The Panel shall make recommendations, based on their analysis, of how to establish, strengthen and maintain NASA QS capabilities for the next 3 decades.
- Task 10. The Panel shall make recommendations, based on their analysis, how NASA should work with universities/industry/Other Government Agencies (OGA)/Federally Funded Research and Development Centers (FFRDCs) and collaborate internationally.

## Team List

| Name                       | Organization                 | Role   | Expertise and notes   |
|----------------------------|------------------------------|--|---|
| <b>Core Team</b>           |                              |  |   |
| Dr. Upendra Singh          | NESC LaRC                    | NESC Lead  | NASA Technical Fellow for Sensors and Instrumentation         |
| Dr. Nan Yu                 | JPL                          | QSCA Task Lead   | Group Lead, CoP lead, Quantum clocks and sensors              |
| Prof Prem Kumar            | Northwestern Univ            | <b>Panel Co-chair</b>                                    | Prof., Quantum and optical communications and sensors         |
| Dr. John Kitching          | NIST                         | <b>Panel Co-chair</b>                                    | Group lead, Chip-scale clocks and sensors                     |
| Prof Ronald Walsworth      | Univ. of Maryland            | Panel Member   | Prof., Clocks, magnetometers, precision measurements          |
| Prof Saikat Guha           | Univ. of Arizona             | Panel Member   | Prof. Quantum communication, imaging, and measurements        |
| Dr. Andrew 'AJ' Metcalf    | US Space Force               | Panel Member   | Program lead, Photonics and clocks                            |
| Dr. Dana Berkeland         | US Government                | Panel Member, ex officio                                 | Atomic devices, clocks, intel community                       |
| Dr. Danielle Braje         | MIT Lincoln Lab              | Panel Member, ex officio                                 | Group lead, Quantum sensors, clocks, and integrated photonics |
| Dr. John Burke             | DoD, OUSD(R&E)               | Panel Member, ex officio                                 | Former AFRL, Clocks and Sensors, navigation devices           |
| <b>Consultants</b>         |                              |  |   |
| Cornelius (Neil) Dennehy   | NESC Technical Fellow Office | NASA Technical Fellow for GNC Representative and Liaison |   |
| Dr. Azita Valinia          | NESC                         | NESC Chief Scientist                                     |   |
| <b>Business Management</b> |                              |  |   |
| Loutricia Johnson          | LaRC/MTSO                    | Program/Financial Analyst                                |   |
| <b>Assessment Support</b>  |                              |  |   |
| Betty Trebaol              | LaRC/AMA                     | Project Coordinator                                      |   |
| Linda Burgess              | LaRC/AMA                     | Planning and Control Analyst                             |   |
| Guy Kimmerly               | LaRC/AMA                     | Technical Writer   |   |
| Leanna S. Bullock          | LaRC/AMA                     | Technical Editor   |   |

# NASA Quantum Sensing Capability Assessment Timeline (2021-2023)



# SAVE- THE- DATE

# NASA Quantum Sensing

# WORKSHOP

## September 27-29, 2022

(September 26 and 30 – Travel Days)

**Newport News Marriott at City Center**

740 Town Center, Newport News, Virginia 23606 [\(Click Here for Hotel Booking\)](#)

NASA is conducting an independent technical assessment of the agency's capabilities in Quantum Sensing (QS) to understand NASA's internal needs and competencies related to QS and compare agency capabilities with those available externally including industry, academia, and other government agencies. The outcome of the assessment will help the agency in establishing appropriate strategies and investments to develop and maintain the state-of-the-art sensing competence and capabilities required to meet the agency's future needs.

### **Workshop Objectives:**

This workshop will involve presentations from leading scientists and stakeholders within the broader Quantum Sensing community and breakout sessions to discuss future directions in Quantum Sensing as relevant to NASA. Questions we hope to address are:

1. What types of Quantum Sensing are being actively pursued within NASA at the present?
2. What activities are being pursued outside of NASA and what is missing from the NASA portfolio?
3. How can Quantum Sensing development efforts from OGAs, academia, and private industry advance NASA objectives?
4. What are the Quantum Sensing needs for future NASA missions?

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National Aeronautics and  
Space Administration



#### **Workshop Co Chairs:**

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**NESC Lead:**  
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#### **Technical Program Co Chairs:**

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## NASA QS Workshop Agenda – Day 1 (September 27)

| Day 1: NASA Mission Needs                           |       |   |   |
|---|-------|---|---|
| Start   | End   | Presenter   | Title   |
| 8:00  | 8:10  | Jessica Gaskin, Deputy to NASA Technical Fellow, Sensors and Instrumentation  | <i>Introduction/Welcome</i>   |
| 8:10  | 8:15  | Dave Young, Deputy Center Director, NASA Langley RC                           | <i>Welcome remarks</i>  |
| 8:15  | 8:30  | Upendra Singh, NASA Technical Fellow, Sensors and Instrumentation, NESC Lead  | <i>"NASA Quantum Sensing Capability Assessment"</i>   |
| 8:30  | 9:00  | Prem Kumar and John Kitching, NASA Panel Co-chairs                            | <i>Workshop Goals and Structure</i>   |
| <i>NASA Mission Needs I: Prem Kumar, Chair</i>      |       |   |   |
| 9:00  | 9:30  | Bhavya Lal, NASA Associate Administrator for Technology, Policy, and Strategy | <i>"Quantum Information Science and Technology - NASA's Comparative Advantage"</i>                                    |
| 9:30  | 9:50  | Carolyn Mercer, NASA Science Mission Directorate                              | <i>"Quantum Sensing for Space Science"</i>  |
| 9:50  | 10:10 | Mario Perez, NASA Astrophysics Division                                       | <i>"Emergent Technologies in Astrophysics: Quantum Sensing"</i>   |
| 10:10   | 10:30 | Pamela Millar, NASA Earth Science Technology Office                           | <i>"Earth Science Measurements and Technologies for the Next Decade"</i>  |
| 10:30   | 10:50 | <b>Break</b>  |   |
| <i>NASA Missions Needs II: John Kitching, Chair</i> |       |   |   |
| 10:50   | 11:10 | Michael Robinson, NASA Biological and Physical Science Division               | <i>"Quantum Sensing the BPS Fundamental Physics Portfolio"</i>  |
| 11:10   | 11:30 | Yousef Chahine, NASA Planetary Science Division                               | <i>"Quantum networks for space-based distributed quantum sensing: Perspectives on planetary science applications"</i> |
| 11:30   | 11:50 | Michelle Munk, NASA Space Technology Mission Directorate                      | <i>"STMD Investment Strategy and Opportunities"</i>   |
| 11:50   | 12:10 | Greg Chavers, NASA Human Exploration and Operations Mission Directorate       | <i>"NASA's Deep Space Human Exploration Plans"</i>  |
| 12:10   | 12:30 | Steven Christe, NASA Heliophysics Division                                    | <i>"The Heliophysics Technology Program and Quantum Sensing"</i>  |
| 12:30   | 2:00  | <b>Lunch</b>  |   |
| 2:00  | 2:20  | <b>Housekeeping &amp; Breakout Organization</b>                               |   |
| 2:20  | 3:20  | Breakout Sessions   |   |
| 3:20  | 3:30  | <b>Break</b>  |   |
| 3:30  | 4:30  | Breakout Sessions   |   |
| 4:30  | 4:50  | <b>Break</b>  |   |
| 4:50  | 5:30  | <b>Breakout Session Summaries</b>   |   |

## NASA QS Workshop Agenda – Day 2 (September 28)

| Day 2: Quantum Sensors Overview                 |       |  |  |
|---|-------|--|--|
| Start   | End   | Presenter  | Title  |
| 8:00  | 8:30  | Organizers   | Recap of previous day  |
| <i>Quantum Sensors I: Danielle Braje, Chair</i> |       |  |  |
| 8:30  | 8:50  | Aaron Weiner, National Reconnaissance Office Advanced Systems and Technology | TBD  |
| 8:50  | 9:30  | John Mather, Goddard Space Flight Center                                     | <i>"Atom Wave Interferometry for Scientific Measurement"</i>                             |
| 9:30  | 9:50  | Scott Luthcke, Goddard Space Flight Center                                   | <i>"Quantum Gravity Gradiometer for Earth Science"</i>                                   |
| 9:50  | 10:10 | Carol Raymond, Jet Propulsion Laboratory                                     | <i>"Quantum Magnetometers in Space: Current Research and Future Directions at JPL"</i>   |
| 10:10   | 10:30 | <b>Break</b>   |  |
| <i>Quantum Sensors II: Ron Walsworth, Chair</i> |       |  |  |
| 10:30   | 10:50 | Matt Shaw, Jet Propulsion Laboratory   | <i>"Superconducting Nanowire Single Photon Detectors for Quantum Sensing"</i>            |
| 10:50   | 11:10 | James Shaffer, Quantum Valley Ideas Lab                                      | <i>"Rydberg Atom-based Sensors – An Introduction and Prospects for Space Deployment"</i> |
| 11:10   | 11:30 | Eric Burt, Jet Propulsion Lab  | <i>"The Deep Space Atomic Clock and Potential Scientific Applications"</i>               |
| 11:30   | 11:50 | Marianna Safronova, University of Delaware                                   | <i>"Optical clocks in space for new-physics discoveries"</i>                             |
| 11:50   | 12:10 | Mukund Vengalattore, DARPA   | <i>"Quantum Opto-mechanics in Space: From Climate Science to Dark Matter"</i>            |
| 12:10   | 1:30  | <b>Lunch Break</b>   |  |
| 1:30  | 1:50  | <b>Housekeeping &amp; Breakout Organization</b>                              |  |
| 1:50  | 2:50  | Breakout Session   |  |
| 2:50  | 3:00  | <b>Break</b>   |  |
| 3:00  | 4:00  | Industry Presentations – see below for order of speakers                     |  |
| 4:00  | 4:20  | <b>Break</b>   |  |
| 4:20  | 5:00  | <b>Breakout Session Summaries</b>  |  |

## NASA QS Workshop Agenda – Day 3 (September 29)

| Day 3: Interagency/Industry Synergistic Activities  |       |  |  |
|---|-------|--|--|
| Start   | End   | Presenter  | Title  |
| 8:00  | 8:30  | Organizers   | Recap from previous day  |
| <i>Synergistic Activities I: John Burke, Chair</i>  |       |  |  |
| 8:30  | 8:50  | Spencer Olson, US Space Force  | "Quantum Sensing at AFRL"  |
| 8:50  | 9:30  | David Reitze, California Institute of Technology                         | "The Laser Interferometer Gravitational-wave Observatory (LIGO): Using Quantum-Enhanced Interferometry to Observe the Most Energetic Events in the Universe" |
| 9:30  | 9:50  | Jeff Livas, Goddard Space Flight Center                                  | "The Laser Interferometer Space Antenna (LISA): Current plans and prospects for quantum sensing in future space-based gravitational wave detectors"          |
| 9:50  | 10:10 | Rob Thompson, Jet Propulsion Laboratory                                  | "NASA's Cold Atom Lab: Four Years of Quantum Science in Space"   |
| 10:10   | 10:30 | Zheshen Zhang, University of Michigan                                    | TBD  |
| 10:30   | 10:50 | <b>BREAK</b>   |  |
| <i>Synergistic Activities II: AJ Metcalf, Chair</i> |       |  |  |
| 10:50   | 11:10 | TR Govindan, NASA Ames Research Center                                   | "Quantum Science & Technology – A Program Manager's Perspective"   |
| 11:10   | 11:30 | Alex Cronin, National Science Foundation                                 | "NSF perspectives and opportunities"   |
| 11:30   | 11:50 | Rima Ouied, Department of Energy/Quantum Economic Development Consortium | "Quantum Sensing Use Cases and Space Demonstrations"   |
| 11:50   | 1:30  | <b>Lunch</b>   |  |
| 1:30  | 1:50  | <b>Housekeeping &amp; Breakout Organization</b>                          |  |
| 1:50  | 2:50  | Breakout Session   |  |
| 2:50  | 3:00  | <b>Break</b>   |  |
| 3:00  | 4:00  | Breakout Session   |  |
| 4:00  | 4:20  | <b>Break</b>   |  |
| 4:20  | 5:00  | <b>Breakout Session Summaries</b>  |  |

## Industry Session – Day 2 (September 28)

|                      |  |   |
|----------------------|--|---|
| Eduardo Oteiza       | Vescent Photonics                      | Deployed optical frequency combs for next-gen PNT solutions                                       |
| Brad O'Brien         | GDMS                                   | GDMS Quantum Sensing  |
| Omar Shehab          | IBM                                    | Identifying benchmarking problems for quantum simulation of nano biosensors                       |
| Lute Maleki          | OE Waves Inc.                          | Tools for Quantum Sensing in Space  |
| Vladyslav Ivanov     | Physical Sciences Inc.                 | Integrated photonics devices for optical quantum networks   |
| Gabe Lenetsky        | Keysight                               | Keysight Solutions for Quantum Sensing  |
| Fraser Dalglish      | L3Harris Tech                          | L3Harris Technologies Space Quantum Sensing Development   |
| Brandon Isaac        | Freedom photonics                      | Photonic devices and components for quantum sensing   |
| Neal Solmeyer        | Honeywell                              | Quantum sensing and timing at Honeywell   |
| Kaitlin Moore        | SRI International                      | Quantum Sensing at SRI  |
| Krishna Rupavatharam | Spectrum Lab, Montana State University | Quantum Supply Chain - Montana Photonics Industry Alliance  |
| Brenton Young        | AO Sense, Inc.                         | Quantum-atomic inertial and gravity sensing   |
| Biju Jacob           | General Electric                       | Silicon Carbide Quantum Magnetometer - How to increase sensitivity with “perfectly imperfect” SiC |
| Hannah North         | ColdQuanta                             | ColdQuanta's Albert: accelerating ultracold atom-based sensor development                         |
| Stephanie Schieffer  | Ball Aerospace                         | TBD   |

## Summary

- NASA Engineering and Safety Center (NESC) Review Board has approved an independent technical assessment of the agency's capabilities in Quantum Sensing (QS) to understand NASA's internal needs and competencies related to QS and compare agency capabilities with those available externally including industry, academia, and other government agencies.
- The External Panel will provide NASA leadership and practitioners an assessment on the technology, value, and identify capabilities, internal and external to NASA, to **lead, leverage and collaborate** to meet NASA current and future needs. The outcomes of the study will help the agency to establish appropriate strategy and investments to develop and maintain the state-of-the-art sensing competence and capabilities to meet the NASA's future needs for science and exploration
- The Panel shall coordinate/collaborate with Quantum Sensing Tiger Team (QSTT) (NASA HQ and relevant Center representatives) to obtain common, current understanding of agency mission needs where QS can be an important enabler for future needs, and any programs, projects, assets, and technologists working in QS.
- The Panel shall assess NASA and External QS capabilities and identify technology gaps, synergies and leveraging opportunities for NASA and partnership opportunities with industry in advancing the TRL of critical QS technologies. The data will be gathered from NASA-sponsored Quantum Sensing Technical Interchange Meeting, targeted to bring NASA QS practitioners from centers, NASA HQ personnel, industry, academia, federally funded research and development centers and other government agencies.
- The Panel shall develop findings and conclusions, including lessons learned and suggested improvements, that describe NASA's state of capability relative to the near-term and far-term mission needs, examples of where NASA is ahead of its peers or working on new, enabling technology, and examples of where NASA is lagging its peers.
- The assessment team will develop findings and conclusions describing NASA's capabilities for the mission needs, NASA's relative position on new, enabling technologies, and an analysis of the gaps that may present any risks to near-term or far-term mission needs.
- The Panel shall make recommendations, based on their analysis, of the most enabling QS areas in short- and long-term for NASA to focus, to establish, strengthen and maintain NASA QS capabilities for the next 3 decades, and highlight synergistic and collaborative opportunity to work with universities/industry/Other Government Agencies (OGA)/Federally Funded Research and Development Centers (FFRDCs).
- The Panel will produce a final report and deliver a presentation to the NESC and stakeholders at NASA HQ and Centers. The duration of the assessment is October 1, 2021, to March 31, 2023.

# Questions?



# BACKUP